ANALYSIS OF SUITABILITY OF CLOSED-SYSTEM WASTE DISPOSAL FOR RECREATION FACILITIES IN SELECTED SEMIPRIMITIVE MOUNTAIN ENVIRONMENTS

AGREEMENT NO. 16-353-CA

ANALYSIS OF SUITABILITY OF CLOSED-SYSTEM WASTE DISPOSAL FOR RECREATION FACILITIES IN SELECTED SEMIPRIMITIVE MOUNTAIN ENVIRONMENTS

Final Report

September 30, 1974

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1. REPORT NO. 16-353-CA	2. GOVERNMENT ACCESSION NO.
	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Analysis of suitability of closed-system waste disposal for recreation facilities in selected semiprimitive mountain environments	5. REPORT DATE September 30, 1974
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Study Investigators	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Agricultural Engineering Divsiion Agricultural Experiment Station University of Wyoming Laramie, Wyoming 82070	10. WORK UNIT NO.
	11. CONTRACT OR GRANT NO. 16-353-CA
12. SPONSORING AGENCY NAME AND ADDRESS Rocky Mountain Forest & Range Experiment Station 240 West Prospect Fort Collins, Colorado 80521	13. TYPE OF REPORT AND PERIOD COVERED Final Report June 1, 1973 - Sept. 30, 1974.
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The effectiveness of a two-cell aerated lagoon system for treatment of vault toilet wastes in the Medicine Bow National Forest of Wyoming was investigated through use of on-site pilot lagoons. Results indicate that BOD was reduced by over 99% with the resulting effluent having very little turbidity, odor, or color. Raising the operating temperature of the first cell by 8 to 15^{o}C did not significantly change the lagoon's BOD removal efficiency or the quality of the effluent when the system was operated for only 30 to 35 days. Irrigation of the effluent onto soil columns with growing native plants caused marked increases in growth rates with no noticable adverse effects and little hazard of groundwater contamination. The design and intended operating procedure of the actual lagoon appear to be sound.

17. KEY WORDS

recreation wastes/treatment facilities/waste disposal/ultimate disposal/ aerobic treatment/ waste water/

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (this report)	21. NO. OF PAGES
	20. SECURITY CLASS (this page)	22. PRICE

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Final Report

1. INTRODUCTION

This document reports on the activities conducted and results obtained during the period June 1, 1973 through September 30, 1974 under the above cooperative agreement.

The objectives of this study were to:

1. Evaluate the technical and economic feasibility of improving aerated sewage lagoon performance by raising lagoon temperatures through the use of a solar heat trap.
2. Identify and evaluate those site conditions--soils, geology shallow water table, and topography--which would limit the practicability of sprinkler irrigation as a final method of disposal for lagoon effluent.
3. Develop guidelines for site location, design, and operation of sprinkler-irrigated disposal fields, especially at high elevations.

The performance of the above objectives was based partly upon the expected completion and operation of the Snowy Range Central Disposal System during the summer of 1973. Since this System was not operational during the 1973 summer, the plan of work of this study was altered and

centered largely upon the completion and operation of an on-site pilot lagoon system. Through use of this pilot lagoon it was possible to evaluate the effectiveness of the planned system and the potential ecological impact of the irrigation water on local vegetation.

2. PROCEDURES

2.1 Description of Actual Lagoon and Vault Toilet Waste.

The two-cell lagoon was designed to receive only vault toilet waste from picnic areas and campgrounds in the Medicine Bow National Forest, Wyoming. The accumulation of vault toilet waste is not expected to be large enough to require hauling until late in the summer of each season; thus, the treatment system will operate only for a period of about 35 days each fall. Loading of the treatment system will be accomplished using a truck with a pump to remove waste from the vault toilets and to haul it to the lagoon. To facilitate the flow of the material through the system, the waste will be diluted with two volumes of fresh stream-water at the time of dump. The dissolved oxygen concentration will be maintained in the system at about 4 mg/l by continuous aeration using surface aerators. After being chlorinated, the effluent from this facility will be applied to the adjacent land by a sprinkler irrigation system.

The vault toilet waste was highly odorous and varied in consistency from a watery liquid to a highly viscous slurry. BOD values obtained from fourteen samples varied from 8,000 mg/l to 35,000 mg/l with an average of 19,000 mg/l. Dissolved and suspended solids content of the waste averaged 20,000 mg/l and 25,2000 mg/l, respectively.

An analysis of metals in the waste, using atomic absorption spectrophotometry, was made on liquid samples from two nearby campgrounds. The HCL-HNO_3 digestion procedure[1] was used. Table 1 presents the results of this analysis.

2.2 Description of Pilot Lagoon System

The pilot lagoon system was constructed using 55 gallon drums. These drums were placed in the ground and backfilled with soil to prevent atmospheric heat loss (Figure 1).

Two separate pilot lagoon systems were constructed. One system was operated at naturally occurring water temperatures (10 to 20^{o}C) while the other was heated to maintain the temperature in its first cell at 20 to 30^{o}C (Figure 2). A submerged, thermostatically controlled, electrical heating element was used as a heat source. Variations in the temperature of the heated cell are explained by the small size of the heating element, variability of the ambient air temperature and cloud cover, and the low temperature of the dilution water.

The two systems were operated identically except for the difference in temperatures maintained in the first cell. Before being loaded, the first and second cells of both systems were filled with dilution water from a nearby stream. At that time dilution water to be used to complete the project was also taken and stored in a 55 gallon drum at the pilot lagoon site.

2.3 Operation of the Pilot Lagoons

Waste used in the pilot lagoons was obtained from a disposal pit

TABLE 1

ATOMIC ABSORPTION ANALYSIS
OF WASTE MATERIAL

Metal	Libby Creek (mg/l)	Barber Lake (mg/l)
Zinc	2.8	4.8
Copper	1	1
Iron	7.5	1.5
Chromium	Negligible	Negligible
Potassium	1890	915
Calcium	232	45
Magnesium	1.2	0.5
Sodium	2550	1400

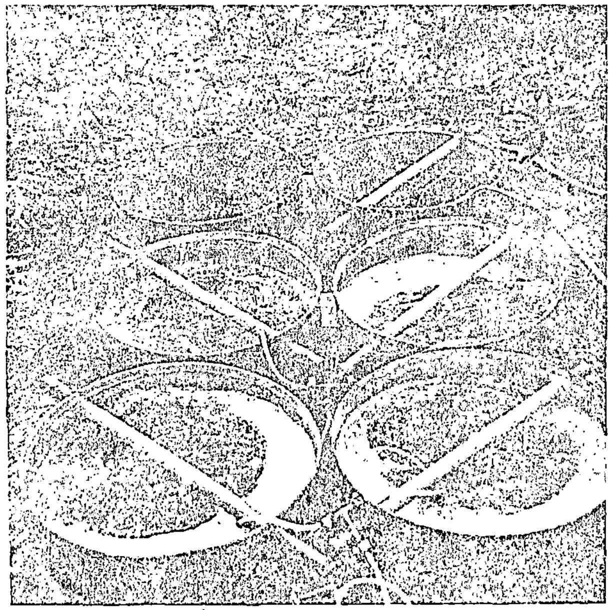

Figure 1. Pilot Plant Layout

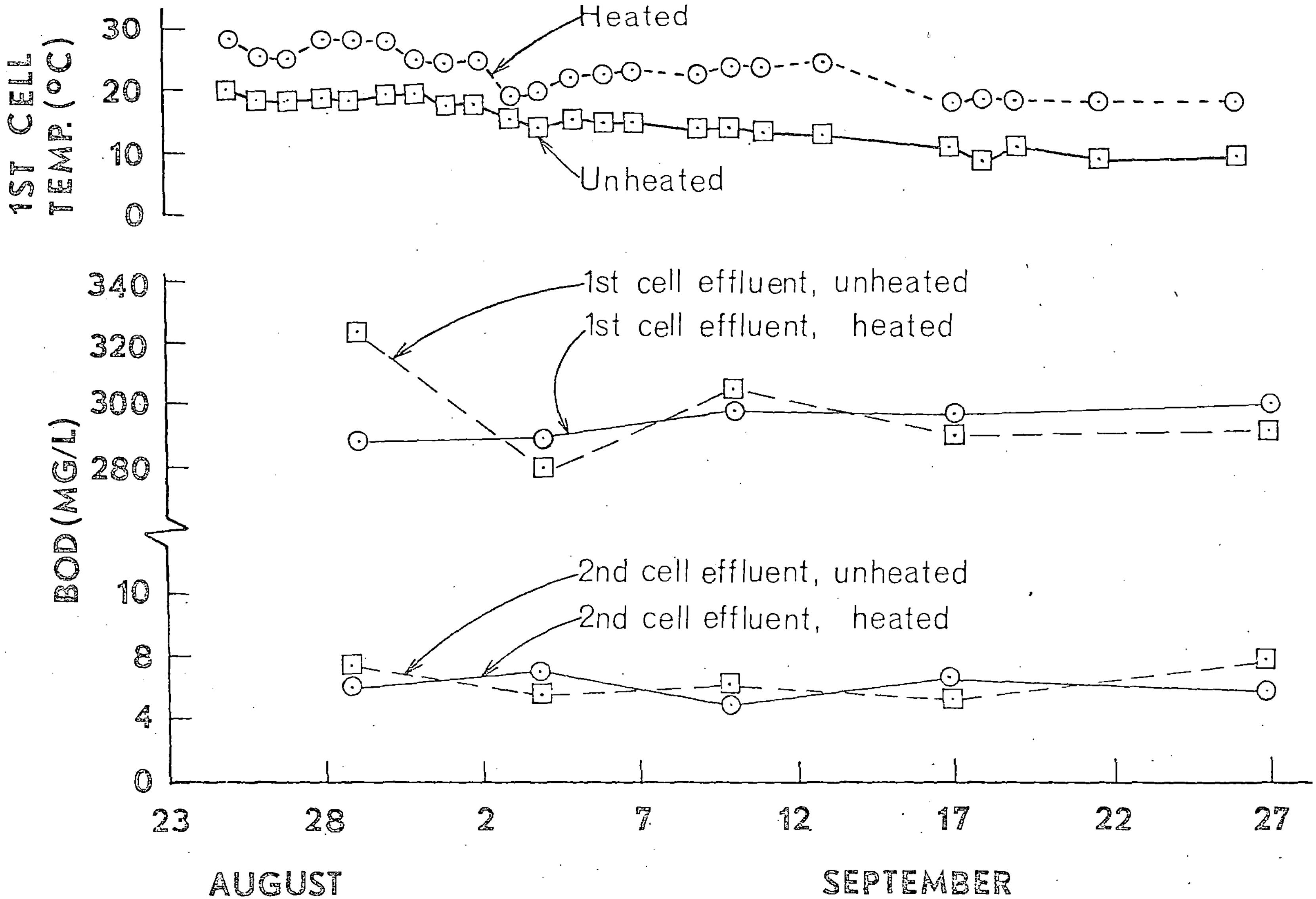

Figure 2. Effluent BOD and Temperature in the Pilot Lagoon

being used by the U.S. Forest Service. BOD of waste from the disposal pit was as stated in section 2.1 and compares closely with BODs obtained from actual pumping trucks as tested by the Wyoming Department of Agriculture Chemical and Bacteriological Laboratory, Laramie, Wyoming.

The influent to the lagoons was applied at a two water volume to one waste volume dilution as a slug load to simulate the dumping operation of the pump truck which would load the actual lagoon. The resulting influent BOD averaged 8,000 mg/l. Application of influent amounted to 1.5 gallons per day added to each system, (700 lb. BOD/acre/day or 15 lb. BOD/1000 ft^3/day). An analysis of this dilution water is given in Table 2. Flow through the lagoon system was accomplished by making bucket-transfers from cell number 1 to cell number 2 at the rate of 1.5 gallons per day.

Continuous aeration was provided using submerged bubble aerators. Although the quantity of air was not measured, sufficient air was supplied to the first cell to keep the solids completely in suspension and to keep the mixed liquor dissolved oxygen concentration of the cell between 1 and 3 mg/l. Dissolved oxygen was measured at periodic intervals using the special alum flocculating procedure[2]. At the end of the operating period, less than 2 cm of residue was found on the bottom of the barrels, which gave assurance that most of the solids had been kept in suspension.

2.4 Application of Pilot Lagoon Effluent to Columns of Soil

Prior to conducting a study in which native forest soil would be sprinkled with pilot lagoon effluent, a preliminary soil investigation was conducted to establish soil conditions. The site where soil samples were taken was well drained. The water table was more than 10 feet below

TABLE 2

WATER ANALYSIS OF DILUTION WATER

Alkalinity	75 mg/l as $CaCO_3$
Chlorides	Not Measureable
Calcium Hardness	36 mg/l as $CaCO_3$
Total Hardness	47 mg/l as $CaCO_3$
Iron	0.08 mg/l as Fe

the ground surface as determined by driving a well point into the sample site.

Soils found on the sample site were typical for mountainous regions in eastern Wyoming. The A horizon was 6 to 8 inches deep and had a sandy loam texture. The B horizon, which was sampled to a depth of 30 inches, was clay loam.

Further analysis of soil samples taken at depths of 4, 12, and 30 inches revealed that the soil contained sufficient trace elements to sustain plant growth. Conductivity of extracts on all soil samples was less than 0.75 million/cm and pH readings of the saturated soil ranged from 6.7 to 7.0. These values have been shown to be very favorable to plant growth[3]. There appeared to be little alkalization because the soil was well drained and the highest exchangeable sodium percentage obtained on all samples was 1.09%.

To simulate irrigation of the forest soils with pilot lagoon effluent, 12 inch diameter soil samples were watered by hand each day with 1/2 inch of pilot lagoon effluent (13,500 gallons per acre per day). Water was sprinkled evenly onto the soil surface at a rate which did not allow surface runoff. The soil was very permeable and water infiltrated at a rapid rate.

The 15-inch deep soil samples were collected by carefully digging around each sample and then sliding a metal cylinder over the sample, thus leaving the original soil structure undisturbed. The cylinders containing the soil samples were placed on a perforated board and their bases were sealed around the circumferences with putty.

3. RESULTS

3.1 Pilot Lagoon Results

The results from the pilot lagoon operation show that excellent BOD reductions can be achieved using the two-cell aerated lagoon. Influent BOD was reduced by 96% (from 8,000 mg/l to 300 mg/l) in the first cell and overall BOD reduction for the system was greater than 99% (Figure 2). After 6 days of operation the lagoons seemed to reach a quasi-steady state in which the BOD of the first cell stabilized at approximately 399 mg/l and the rate of mixed liquor suspended solids buildup in the first cell decreased significantly. Mixed liquor suspended solids continued to increase slowly after 6 days of operation (Figure 3) in the first cell, but this did not significantly influence the effluent quality. Heating in the first cell did not significantly improve the lagoon's performance.

Periodic chemical analyses of the effluent from the unheated system were performed during the testing period (Figure 4). All tests with the exception of phosphate and chloride were conducted according to Standard Methods for the Examination of Water and Wastewater.[2] Phosphate and chloride concentrations were determined using the DR-EL-2 Engineer's Laboratory made by the Hach Chemical Company, Ames, Iowa. The measured chemical constituents of the effluent increased over the period of operation and were increasing in concentration at the end of the testing period, even though BOD reduction had stabilized. Therefore, a prediction of nutrient and sodium content in the effluent cannot be made unless both loading and length of the lagoon operation are considered. However, since the operation of the actual lagoon will last only about 35 days, it is felt that the data shown in Figure 4 depict what will actually occur in the unit. The effluent produced from both the heated and unheated systems was a clear, odorless, slightly yellowed colored liquid.

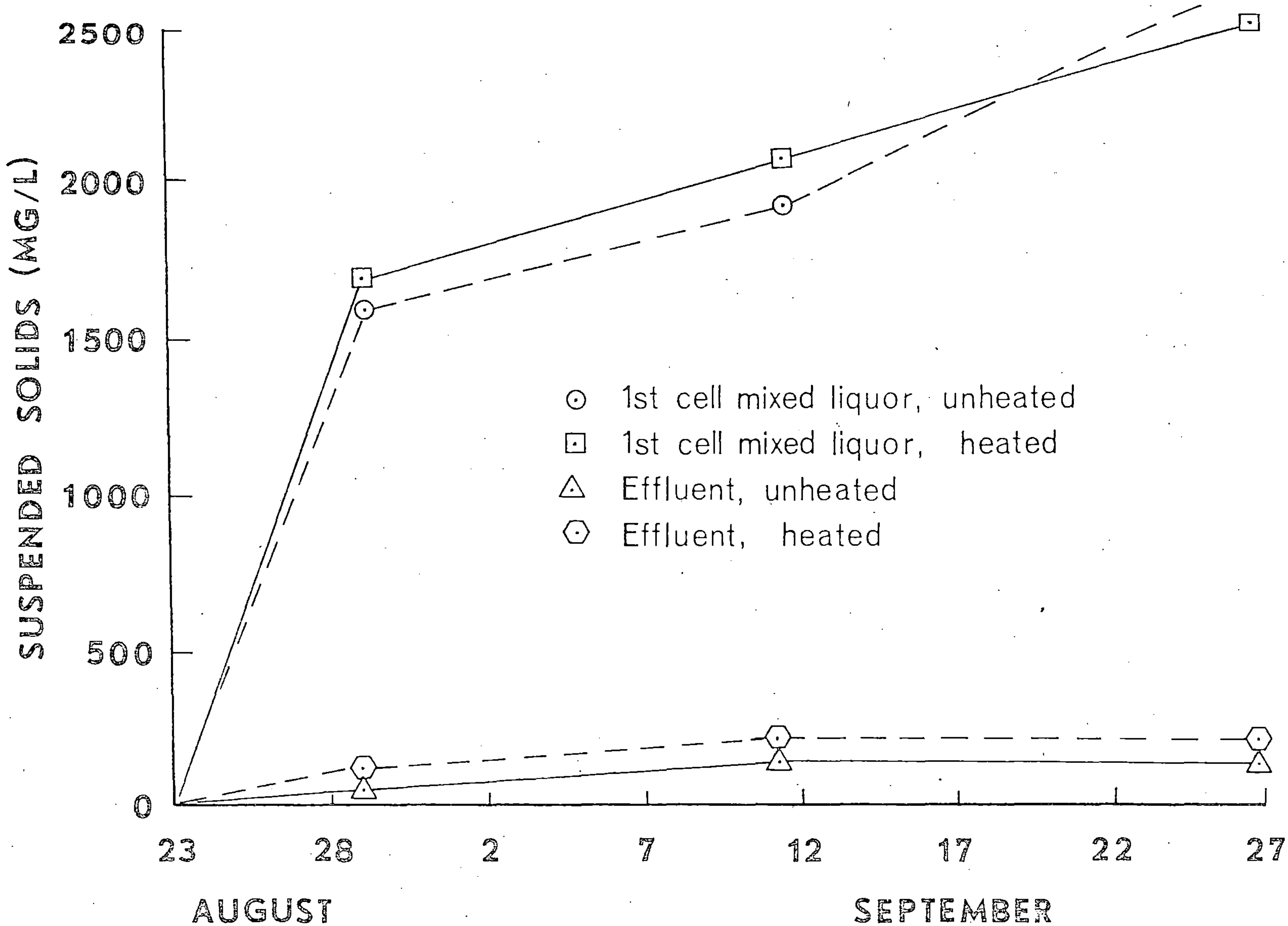

Figure 3. Suspended Solids in the Pilot Lagoon

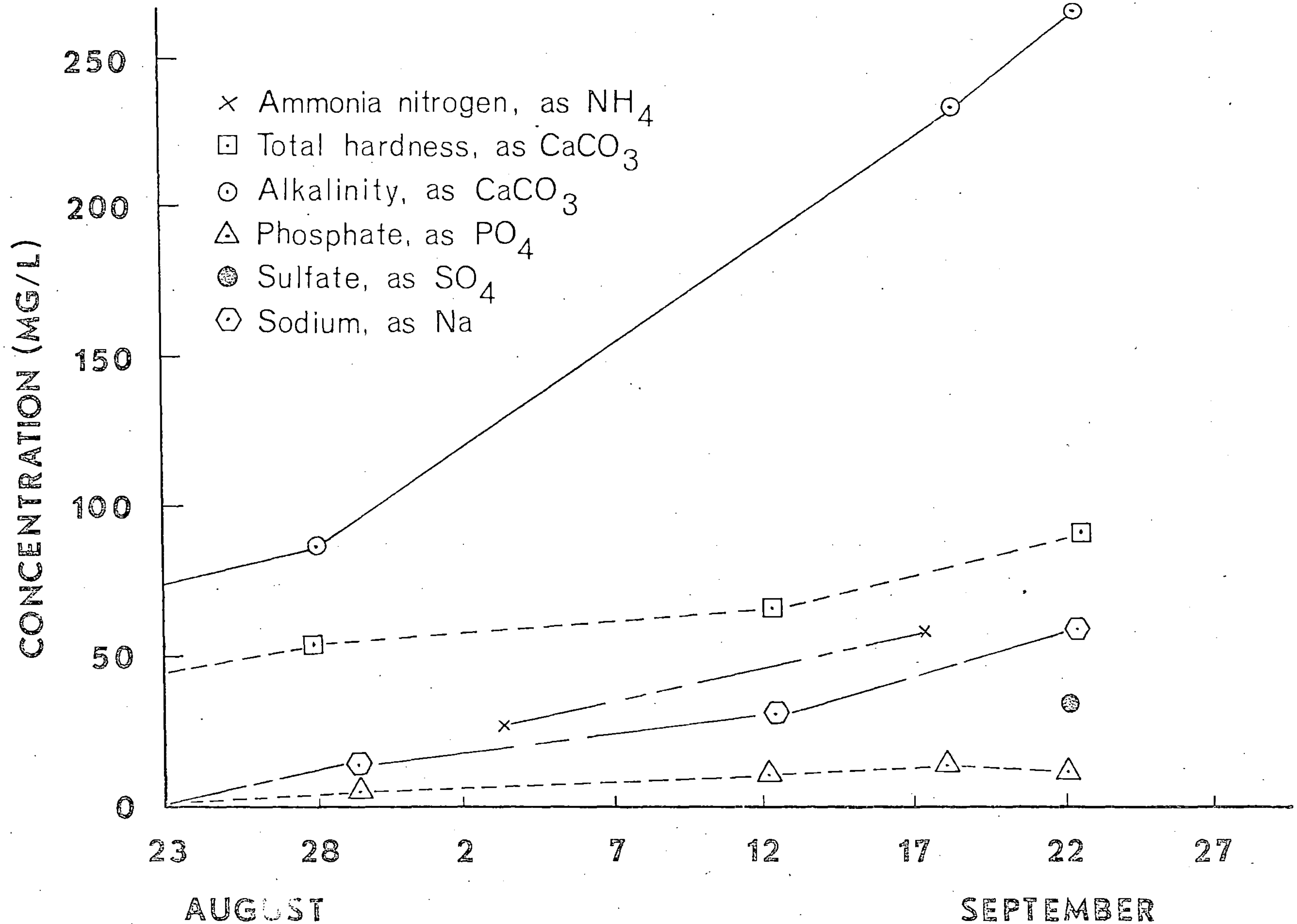

Figure 4. Effluent Analysis of the Unheated System

3.2 Plant and Soil Response

Plant response in the cylinders which received effluent was favorable. All species benefited from the increased moisture loading with the flat-bladed grasses flourishing most visibly. In a control cylinder which received only natural rainfall, most of the vegetation appeared brown and dormant. In the cylinders receiving waste water, the flat-bladed grasses grew to about 4 inches high in the 39 days and were very green. Wild flowers bloomed during the irrigation period and mosses became much more abundant.

After the irrigation period, a soil analysis was performed on both the irrigated cylinders and the control cylinder (Tables 3 and 4). It appears that the wastewater had little detrimental effect on the soil medium. As shown in Tables 3 and 4, the measured soil parameters of the irrigated and non-irrigated or control cylinders do not show excessive differences in soil properties. Exchangeable sodium percentage changed very little during the course of wastewater application (from 1.09% to 1.64%). Therefore, it appears that the design application of wastewater presents little danger of alkalization over a 20 year design period. Nitrate and phosphate concentrations were comparable in both the irrigated and non-irrigated cylinders. The testing did indicate, however, that sodium may be slowly replacing calcium and magnesium in the soil cation exchange structure. In the irrigated soil column, calcium and magnesium ions seem to be moving downward, while sodium seems to be increasing in the upper soil horizon. Sodium build-up should be monitored closely as the long range effects of sodium build-up can render the irrigation site useless.[4]

TABLE 3

SOIL ANALYSIS
UNIRRIGATED CYLINDER

Time: End of application period

Test	2" Sample Depth	12" Sample Depth	Test Method Used	Reference
pH	6.7	6.4	Saturated Extract	4
Organic Matter %	6.7	0.5	Walkley-Black Method	5
Phosphate ppm	2.0	9.0	Ascorbic Acid	6
Nitrate ppm	2.5	5.0	Phenoldisulfonic Acid	8
		Ammonium Acetate Extractable Cations meq/100 gms		
Calcium	14.6	9.3	Atomic Absorption	9
Magnesium	2.5	5.0	Atomic Absorption	9
Sodium	0.1	0.2	Atomic Absorption	9
Potassium	1.7	1.3	Atomic Absorption	9
Cation Exchange Capacity meq/100 gms	19.4	18.0	Sodium Acetate Extraction	4

TABLE 4

SOIL ANALYSIS
IRRIGATED CYLINDER

Time: End of application period

Test	2" Sample Depth	12" Sample Depth	Test Method Used	Reference
pH	6.8	6.8	Saturated Soil	4
Organic Matter %	5.1	0.42	Walkley-Black Method	5
Phosphorus ppm	5.0	10.0	Ascorbic Acid	6
Nitrate ppm	5.0	1.25	Phenoldisulfonic Acid	7
	Ammonium Acetate Extractable Cations meq/100 gms			
Calcium	15.20	25.00	Atomic Absorption	9
Magnesium	2.25	4.60	Atomic Absorption	9
Sodium	0.33	0.06	Atomic Absorption	9
Potassium	0.72	0.60	Atomic Absorption	9
Cation Exchange Capacity meq/100 gms	20.2	32.0	Sodium Acetate Exchange	4

3.3 Evapotranspiration From And Percolation Through The Soil Samples

Prior to saturation of the soil with water, daily weight measurements were made on the cylinders in an effort to determine evapotranspiration. The cylinders were watered and weighed daily. Then, after sitting overnight, the cylinders were weighed again at the same time the next day. The average weight change per day, exclusive of rainfall, amounted to 175 grams of water or 0.275 inches. This means that 54% of the water applied was lost to evapotranspiration.

At a loading rate of 1/2 inch per day, 39 days were required for water to percolate to the bottom of the 15-inch deep cylinders. Since the opertional period of the pilot lagoon is set at approximately 35 days each season, most of the wastewater applied will not percolate past the 3 or 4 foot depth but should be evaporated or used by plants.

Samples of water which had percolated through the 15-inch deep soil cylinders were obtained by applying a vacuum to the bottom of the cylinders after the soil had become saturated. Immediately after the samples were obtained, they were cooled in an icewater bath to retard biological action and were returned to the University of Wyoming's campus for analysis.

As indicated by Table 5, the BOD of the percolating water actually increased after passing through the soil. BOD of the lagoon effluent was 6 mg/l while samples taken from the soil cylinders averaged 60 mg/l BOD. BOD increase of the soil filtrate could have been caused by the conversion of ammonia nitrogen to nitrate. It is possible that organic matter was leached out of the soil and into the sample collector. The soil cylinders removed 86% of the nitrates from the waste water and 96% of the total

TABLE 5

WATER ANALYSIS

Test	Effluent from Unheated System	Water after passing through 12" soil column
pH	7.5	6.9
Specific Conductance millimhos/cm	0.92	0.54
Total Phosphate ppm	8.0	0.3
Ammonia Nitrogen ppm	66	9.4
Nitrite Nitrogen ppm	0.09	No Indication
Nitrate Nitrogen ppm	0.14	No Indication
BOD mg/l	6	60

Note: Due to the small amount of filtrate obtainable from the soil columns, water analyses for nitrogen and phosphorus were conducted using the DR-EL-2 Engineer's Laboratory made by the Hach Chemical Company, Ames, Iowa.

pH, Specific Conductance, and BOD were run in accordance with Standard Methods for the Examination of Water and Wastewater. (ref. 2)

phosphorus. Virtually 100% of the coliform organisms were removed by the soil medium. Coliforms averaged between 100 and 200 organisms per 100 ml in the unchlorinated effluent and zero organisms per 100 ml in the unchlorinated water after it had percolated through the 15 inch deep soil cylinders.

4. DISCUSSION

4.1 Objective 1

Raising the operating temperature of the first cell of the two-stage pilot lagoon by 8 to 15 degrees centigrade, as could be expected using a solar heat trap, did not significantly change the lagoons' performance. Although the overall BOD reduction of the system was greater than 99%, even without heating, differences in the rate of reduction might have been observed if the system had been operated longer. A greater rate of reduction would result in a higher allowable loading rate or a smaller design size. Perhaps the organisms involved did not change their respiration rate in the temperature ranges studied here or they required longer than 30 days to acclimate to the sudden temperature change. Recent research by Benedict and Carlson[5] seems to support the theory that mixed culture, aerobic organisms do not significantly change their respiration rates in the temperature range studied. The research of Marais and Shaw[6] also supports the conclusion that temperature changes in the regions studied do not have a predictable effect on the BOD reduction efficiency or the reaction kinetics of the system.

4.2 Objectives 2 and 3

Excellent BOD reductions were achieved using the two-cell aerated pilot lagoon. Influent BOD was reduced by 96% in the first cell and by

99% for the overall system. Based on the fact that BOD reduction efficiency was so great, it appears that the lagoon system could receive a much higher rate of loading and still achieve adequate BOD reductions.

The factor limiting the loading rate might be the resulting salt concentration in the effluent. An increase in salt concentration in the effluent could have undersirable effects on the soil structure and plant life of the irrigation field. The pilot lagoon operation showed that the possibility of increased soil salinity and alkalization is actually quite low. If operated at a discharge rate of 1/2 inch per acre per day, or less, the irrigation field should remain in good condition. However, as a precaution, soil salinity and exchangeable sodium percentage should be included as part of the monitoring routine of any sewage effluent irrigation project.

Hazards of groundwater contamination by this type of treatment system are extremely low as shown by the absence of coliform organisms found in the soil percolate after passing through the first 15 inches of soil. It is emphasized here that the effluent used in this irrigation study was unchlorinated and that, in an actual operation, the effluent would be chlorinated prior to irrigation. This means that the coliform content of actual lagoon effluent should be drastically reduced from what it was in the irrigation experiments. Very little water percolated past the 15-inch depth over the annual operating period of the lagoon, and the water table on the actual site is still more than 9 feet below that depth. Hazards of nitrates and phosphates percolating into the groundwater are extremely small as they are largely removed in passing through the first 15 inches of topsoil.

Native plants thrived on the increased water and nutrients contained in the pilot lagoon effluent. After 30 days of irrigation, plants under irrigation showed noticable growth and increase in vitality as compared to non-irrigated plants.

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